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Working With Gifted Science Students in a Public High School Environment:

One School's Approach

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The Chemistry/Physics Program at Evanston Township High School was designed to provide an environment for the rigorous teaching of advanced science and mathematics to accelerated students. This type of student makes up the bulk of students in the Advanced Placement Chemistry and Physics classes. However, there is a small number of students who master class materials quickly and easily and display unusual scientific insight. We consider these students to be gifted, and it is this group on whom we have reported in this article. We discuss various options we have utilized to keep students in the Chemistry/Physics Program highly motivated and challenged.

The Chemistry/Physics Program at Evanston Township High School was designed in 1952 to provide the most advanced and motivated science students with a challenging college-preparatory science experience. This is a demanding and rigorous study of physical science and mathematics that extends over a 3-year period, beginning in 10th grade. During this year, students take a full year of combined high school honors chemistry and physics at an accelerated pace. In grades 11 and 12, students take college-level chemistry and calculus-based physics during alternating semesters. Until recently, most students in this program would also take calculus (advanced placement Calculus BC) and advanced multivariable calculus during this time. In general, students selected to participate in this program are bright and highly motivated. They are usually ranked in the upper 5% of the student body (school population 3,100).

Each year, however, there is a smaller subset of these students who tend to have exceptional talents in mathematics and science that noticeably exceed those of the typical student in our Chemistry / Physics Program. They tend to master mathematics and science concepts quickly. They are inquisitive, and they tend to display a scientific insight that is far superior to that of most individuals. We classify students in this group as gifted in science and mathematics, while the bulk of the students in our program can be classified as accelerated students.

Just what are the criteria used in identifying a student as gifted? Some educators may label a student who gets top scores on a science assessment tool as being gifted in science. Others may consider a student who consistently maintains a perfect score in a yearlong course as gifted. We present other criteria that we have used to identify gifted students in our Chemistry/Physics Program. We also discuss the different approaches that we have used to keep these students highly challenged and motivated.

Concept Attainment and Gifted Students

The approach we have taken in building the curriculum for our Chemistry/Physics Program has been the emphasis on the attainment of key scientific concepts. Because of the interdisciplinary nature of the program, it was decided to identify key concepts that are necessary to the mastery of chemistry and physics. Examples of concepts that were identified in this category include the concepts of an atom, of force, of energy, and of rate, just to name a few. The importance of these concepts in understanding chemistry and physics is undeniable. One can not discuss Newton's laws of motion without introducing the concept of rate. Likewise, the study of rate of chemical reactions is a major area of study for all aspiring chemists. The concept of force is equally fundamental to the understanding of physics and chemistry. One needs to understand the concept of force in order to understand the concept of bond length in chemistry. The study of intermolecular forces of attraction between molecules is another example that illustrates the importance of this concept in mastering chemistry. These and other concepts are introduced to the students throughout the 3-year sequence of the Chemistry/Physics Program.

Many scientists and science educators have always recognized the need to build scientific knowledge around conceptual schemes. Jackman proposed as far back as 1904 an elementary science curriculum that emphasized the understanding of scientific concepts. Conant (1947), in his writings and reports, also recommended the use of concepts as the major building blocks for the structure of science curricula. Concepts are very important in all areas of science for several reasons. They can be used as legitimate means for organizing scientific facts into meaningful entities. This is the approach that was taken in the Science Department at Evanston Township High School when a physics course known as Conceptual Physics was created for students weak in mathematics. In this course, students are exposed to major physics concepts without requiring rigorous mathematical treatment. These concepts can also be used to integrate scientific knowledge across the various areas of science and facilitate the transfer of learning to new situations.

Indeed, many studies have shown that transfer of learning is greatly facilitated by organizing learning experiences around concepts. Kuslan and Stone (1968) stated to this effect: "Learning which is conceptually oriented is much less likely to be forgotten than learning of isolated facts and principles" (p. 80). The same argument was also espoused by Allport (1938) when he stated that "only when a general principle is understood as applicable to two or more fields does the training in one carry over to the others" (p. 277).

If concepts do facilitate transfer of learning, it is more likely that concept attainment or formation occurs when a student begins to generalize from specific instances of a concept to a class of such instances. This generalization process requires transfer of learning from a specific to a whole class of instances of a given concept. Students who can transfer learning of a given concept are generally referred to as having great insight. For instance, in physics, it is one thing to be able to learn details about a specific force like gravity, but most students are not able to take the next intellectual step and make a connection between gravity and all other forces. This step would include understanding both similarities and differences between gravity and other individual types of forces at both the conceptual and mathematical levels. A gifted student on his or her own may be able to identify a deeper connection between gravity and electromagnetic forces through the fundamental concept of flux and fields or perhaps understand the difference between gravity and the strong nuclear force when introduced to a concept called "asymptotic freedom." These identifications are made through highly abstract mathematical reasoning, and typical Advanced Placement students (i.e., accelerated students) are not able to think at this level.

We have used this ability to transfer learning from specific instances of a concept to a whole class of such instances as a means of distinguishing between gifted and accelerated students. In fact, gifted students display superior scientific insight compared to accelerated students because of their concept attainment, which allows them to transfer learning from specific instances of a concept to a whole class of such instances. We have also used the ability to apply attained concepts to solve problems at high levels of cognition as evidence of being gifted. Such an ability requires mastery of both concrete and abstract reasoning.

Because of their mastery of abstract reasoning, gifted students in the physical sciences also tend to excel in the area of mathematics. The students whom we have identified as gifted in science can identify instances of concepts that were previously learned with great ease in our Chemistry/Physics Program. The gifted students tend to have taken AP Calculus BC at least by grade 7 and some even by grade 9 or 10. In grade 12, they usually take Multivariable Calculus. Some even take higher level mathematics as independent studies. Still others go to Northwestern University to take more advanced mathematics classes.

Accelerated students, on the other hand, are those with an above-average intellectual ability who usually attain concepts by a combination of talent, acquisition of skills through repetitive drills, and hard work. They usually have a mastery of concrete reasoning, plus a fair amount of abstract reasoning. They are typically not as advanced mathematically as those whom we have labeled as gifted. They tend to take AP Calculus AB or BC by grade 12. It should be noted that AB Calculus is a full-year AP course that covers materials that are typically presented during the first semester of BC Calculus. On the other hand, BC Calculus is a full-year AP course that is taught at a faster pace and covers materials generally taught in the first-year two-semester college calculus course.

One may wonder just what evaluation process we use in distinguishing gifted from accelerated students. Rather than using a standardized test to distinguish gifted students from accelerated ones, we have relied on teacher anecdotal records as a means of identifying gifted students in our Chemistry/Physics Program. The following example will illustrate how we have used anecdotal observations to identify gifted students in our program.

Three years ago, we had a student who had quickly mastered the concepts related to electromagnetism and the fact that time-dependent electric fields "turn on" magnetic fields and vice-versa. One day, after this material had just been introduced, he came to one of us and brought up the idea that something similar should happen with time-dependent gravitational fields since so much of the mathematical foundation was similar to that of electromagnetism. Because of his superior scientific insight due to concept attainment, this student was able to think in mathematically abstract terms. For this reason, he was allowing himself to develop independently the concept of gravitomagnetism that Albert Einstein had predicted. A typically accelerated student would not be able to think in such abstract terms and would not be able to apply this kind of reasoning to something so physically different, yet conceptually similar. The accelerated students are not as likely to make connections between the concepts that they have learned in class with other phenomena outside of the curriculum due to their limited scientific insight.

The Chemistry/Physics Program is a 3-year program that begins in 10th grade. This means that students enrolled in the program must be identified at the end of their freshman year. Up to about 10 years ago, the Science Department at our high school offered a course called "Life Science Honors" (LSH) in the freshman year. This course emphasized the use of the inquiry approach to teach biology to freshmen. Prospective students for the Chemistry/Physics Program were identified from this class. Success in Life Science Honors course (a grade of B or better) and success in Honors Freshman Mathematics (on track to take Calculus by the senior year) were some of the requirements that a student had to fulfill in order to be invited in the Chemistry/Physics class. Other requirements included a favorable teacher recommendation and success on the California Achievement Test (CAT). A 90th percentile or higher on the CAT was required to qualify for the program.

About 10 years ago, the freshman Life Science Honors course and the sophomore Biology Honors course were combined to produce a single Biology Honors course for the freshman year. This is the only science course that has been taught in the freshman year for the last 10 years. Placement for Biology Honors is done by teacher analysis of student skills and success on the ACT Explore Test. The chairperson of the Science Department bases his decision on student performance on all the four sections of the Explore Test. He usually selects students in the top three stanines, that is, in the 77th percentile or higher.

For admission to the Chemistry/Physics program, the Science Department chairperson relies on teacher recommendations from the Biology Honors course and documented success in mathematics. Students who are strong in mathematics and who are headed to taking Calculus by their senior year are highly sought for the Chemistry/Physics Program. Lately, success in mathematics has become a stronger indicator for appropriate placement in the program.

After the students join the Chemistry/Physics Program during their sophomore year, we start to compile teacher anecdotal records on each one of them. Students who display an outstanding scientific insight are identified as gifted. We have found that it is not possible to place this label on students based on other, more objective criteria such as test scores. High scores on tests are not always indicative of a student's scientific insight. Each year, there are usually 5 to 10 students whom we identify as gifted.

Recent Changes in the Chemistry/Physics Program

When the Chemistry/Physics Program was first started in 1952, gifted students made up a larger percentage of the students in the program than we have today. This kind of student body played a major role in the decision that was taken with respect to the organization of the program. Students who were going to begin the program in grade 10 were identified by middle school teachers in grade 8, and all took Honors Biology in grade 9. The decision to teach both Chemistry and Physics Honors in one year (grade 10) was based on the fact that students would be exposed only to the major conceptual schemes in chemistry and physics and that they would then investigate details of these concepts on their own. Typical enrollment was 30 to 40 students, and all of these students went on to take the AP courses in grades 11 and 12. The majority of the students were quite mathematically advanced and would take Multivariable Calculus and Linear Algebra by their senior year.

In the past few years, however, the number of gifted students and mathematically advanced students has remained about the same, while the total enrollment in the program has increased dramatically after it was decided to open it up to all who wanted to try. All students in grade 9 now take Biology, with between 150 and 200 taking Honors Biology. For example, 2 years ago, there were nearly 120 students who took the grade 10 honors course, and about 90 went on to begin AP courses in grades 11 and 12. The teaching has also become geared toward the accelerated students who make up a larger portion of the student body. There is a danger that the gifted students would become bored with the slower pace suited for the accelerated students.

In order to keep the gifted students continuously challenged, other curricular options had to be considered.

Options for the Gifted Science Student

Once we identify gifted students, we encourage them to get involved in a variety of challenging academic and research-based activities. For example, students who are advanced in mathematics may be encouraged to take more advanced mathematics classes at Northwestern University. Sometimes, students choose to carry out an independent study by developing their own course with a sponsoring teacher at the high school. For those students who are looking for an even greater challenge, we provide them with opportunities to carry out original research studies in the physical and biological sciences. Most of these research studies are conducted in our own high school laboratories. Lately, a small number of our students have also had a chance to work with some professors from Northwestern and Loyola Universities.

Types of Independent Studies

We provide gifted students in the Chemistry/Physics Program three kinds of independent studies.

Students can choose to take an entire course as an independent study and receive high school credit. If the course that a student desires to take is not offered by the high school, he or she may take the course at Northwestern University. However, a student can also elect to take the course inside the high school if a high school teacher qualified to teach the course can be found. For example, several years ago, we had two students who had taken all the advanced mathematics courses (Linear Algebra, Multivariable Calculus) our school offered. Because they wanted to take more advanced mathematics courses, they decided to take Group Theory as an independent study with one of the faculty members in the Mathematics Department.

The second type of independent study is an outgrowth of special interest that students develop in the topics discussed in our Advanced Placement Chemistry and Physics courses. In Advanced Placement Physics, for example, several gifted students usually choose to study relativity and higher-level Lagrangian mechanics in more depth simply to satisfy their intellectual curiosity. It is also not unusual to have students who choose to study quantum mechanics in more depth in Advanced Placement Chemistry. Students do not receive extra credit for this type of independent study, but this does not prevent gifted students from engaging in these intellectual endeavors. They carry out this type of independent study for the intellectual challenge it represents.

The last type of independent study involves some types of hands-on activities. This may involve laboratory or computer work or a combination of both. In Advanced Placement Chemistry, for example, students have studied oscillating reactions as an independent study. Others have used molecular modeling via computer to investigate the crystal structure of benzene. In Advanced Placement Physics, for example, students have written their own computer programs to simulate various chaotic mechanical devices and fractal generators.

From the above discussion, one can see that nurturing gifted students' intellectual prowess presents an additional challenge for the teachers. In addition to the time needed to plan for actual coursework, the teacher also needs time to plan for the independent studies offered to students. This may require 2–3 more hours of planning each week. Excellent teaching of gifted students requires total commitment on the part of the teacher.

Extracurricular Academic Competitions

We have also used extracurricular academic competitions as a motivating tool to keep our students continuously challenged. A large portion of area high schools (including ours) are involved in some kind of academic competitions where individuals and groups of students are tested on their knowledge and problem-solving abilities. Some of the more popular ones among these include the Scholastic Bowl, Mathlete Math Contest, Junior Engineering and Technical Society (JETS), Worldwide Youth in Science and Technology (WYSE), and the National Science Bowl. We have been actively involved with JETS, WYSE, and, more recently, the Science Bowl, and our more advanced students have done very well in these competitions at the regional, state, and national levels.

Our experiences have shown us that the majority of the gifted students are naturally attracted to academic competitions because they provide them with an opportunity to show how much they really know (and sometimes discover what they do not yet know). However, not all gifted students are competitive, and some do not want to get involved in a head-to-head competition with other gifted students from other high schools because they are afraid of failing for the first time in their lives.

While it is important to respect a student's choice to not participate in some academic competitions, students need to be made aware that the world outside the high school walls can be fiercely competitive and that the chances of failure at some point in their lives are real. As Rimm (1995) has suggested, children actually develop self-confidence through struggle and become achievers only if they learn to function in competition, which is a side of competitions many teachers ignore.

For gifted students who are afraid of head-to-head and individual competitions, we have used other forms of academic competitions to keep them challenged. For example, the American Association of Physics Teachers (AAPT) sponsors the Physics Bowl and Physics Olympiad competitions each year. In a similar manner, the American Chemical Society (ACS) sponsors the Chemistry Scholarship and Chemistry Olympiad competitions each year. These competitions are exam-based; therefore, students are not faced with the threat of failure present in head-to-head competitions. Rather, these are competitions that look for high levels of knowledge and strong problem-solving skills. In the case of the Physics Bowl, there are both individual and team scores with some scholarship money for the highest scores. The Chemistry and Physics Olympiads ultimately determine the U.S. Chemistry and Physics Teams that compete internationally.

Student Independent Science Research

For gifted students who want to be truly challenged, they can elect to carry out original research in the major scientific disciplines. For a long time, the results of such research were submitted to the National Westinghouse Science Talent Search and the Junior Science and Humanity Symposium (JSHS) Competitions. The Science Service in Washington, DC, administers the National Science Talent Search. The Junior Science and Humanity Symposium is a program of the U.S. Army that is locally administered by the Department of Biology at Loyola University. There are regional sites for the JSHS in almost every state. Today, the Westinghouse Corporation no longer provides funds for the National Science Talent Search Competition. The funding has been taken over by the Intel Corporation. Hence, the old National Westinghouse Science Talent Search is known today as the Intel Science Talent Search. It is regarded as the most prestigious science competition for high school seniors. A relative newcomer to the list of national science research competitions is the Siemens-Westinghouse Science and Technology Competition. Both of these competitions provide a maximum of $100,000 in scholarships for the top research report paper. The Siemens-Westinghouse Science and Technology Competition has the added feature of two-person teams who work together on science research, and the top award for a team is $90,000. With this kind of money available to top students, it has become easier to find students who are willing to allocate the large amount of time necessary to carry out a viable science research project.

All the research projects that were carried out by our students from the '50s to the late '90s were done in the high school laboratories or in the students' homes. Many of the projects made use of equipment built by the students or used computer programs they had written themselves. We truly believe that it is still possible for students to do real science in a high school laboratory in spite of limited budgets. In our humble opinion, we find it unfortunate that the various national science competitions have lately tended to favor only student research projects that were done in university laboratories. In these settings, high school students often join a research project already in progress. They usually end up missing much of the research process that takes place prior to actual research activity, particularly the development of a research question and the experimental design process. Fortunately for our high school, to date, only one of our national semifinalists in the Science Talent Search (out of nearly 180 national semifinalists Evanston has had over the years) and three semifinalists in the Siemens-Westinghouse Science Talent Search have worked with professors from Northwestern University. The topics of these projects included cancer treatments and designing biomimetic peptoids that serve as lung surfactants. Clearly, these research topics could not be carried out in a high school setting due to the sophistication of necessary equipment and funding.

In our Chemistry/Physics Program, we do not require students to carry out an original research project. Instead, teachers go into freshman and sophomore science classes to present ideas about doing science research for the Intel and Siemens-Westinghouse competitions. Interested students are then encouraged to contact the teachers. Gifted students with a strong interest in science are usually encouraged to come up with their own topics for potential research projects.

In order to help these students come up with possible areas of research, we usually make available to them papers of past research studies. We also have a list of potential research topics developed by science faculty members who comprise an advisory faculty research team that we keep on hand. Students are also encouraged to browse through this list to see if they may be interested in some of the topics for a potential research area.

After a student selects a potential topic, he or she is then paired with an appropriate high school science faculty member who has research experience. The student and faculty advisor immerse themselves in the literature to learn as much as possible about the topic, as well as previous research in that area. A specific, focused research question is then developed that will become the focal point of the research project. It then becomes the responsibility of the student to develop a research plan that includes forming a hypothesis to answer the research question; design a physical experiment, theoretical computer simulation, or both to test the hypothesis; and then perform an extensive analysis of data to reach sound conclusions. Students try to complete a report on their research experience in time for submission deadlines for various competitions. This whole process normally takes about 1 full year, and most advanced and gifted students who choose to take on this challenge begin early in grade 11, although they are encouraged to begin the process even sooner.

Each teacher who supervises science research projects in the Chemistry/Physics Program usually has one to three students under his or her supervision. Some teachers have been able to supervise up to five students, but we have found that, for an effective supervision, that is the maximum possible number. Examples of topics that have been investigated in chemistry include studies of molecular rearrangement, such as the effect of mole ratio of catalyst to substrate on the Fries Rearrangement of thymyl acetate and designing novel methods for the synthesis of selected organic compounds by the electrosynthetic method, just to name a few. In physics, studies of heat flow through materials, fluid dynamics, the properties of granular materials, and numerous other topics have helped provide a rich and diverse research program. Research studies culminate in the submission of a 20-page, double-spaced research report to the Intel Talent Search or to the Siemens-Westinghouse Science and Technology Competition.

The Science Department provides most of the materials used in the research by the students. Teachers who supervise research receive an extra stipend from the Board of Education of District 202. Our faculty research team is relatively new, as we have begun to take an approach that is modeled after university research groups. Faculty members who have research experience and are from a variety of disciplines meet regularly to discuss individual student progress, new research topics, and long-range planning for science research in the high school. Such an approach allows for a larger variety of potential projects, as well as an emphasis on the interdisciplinary nature of model science research in the real world. In addition, we have greater contact with more students who may want to pursue research and have begun to get more freshman and sophomore students involved in research, thus giving them more time to develop and refine a project before submitting it to a competition. We have recently begun a research class that freshmen can take to learn about the scientific method as well as begin to develop ideas that they may investigate in the lab over an extended period of time.

Conclusion

Because gifted students can easily and quickly master topics discussed in a typical Advanced Placement Chemistry or Physics class, there is a danger that they may become bored if other options are not utilized. At Evanston Township High School, we have used a combination of independent studies, extracurricular academic competitions, and independent science research projects to keep our gifted students in the Chemistry/Physics Program continuously challenged and motivated. Gifted students need more than standard classroom activities because these can be too easy for them. Our experience shows that gifted students appreciate a variety of additional learning activities because they have many interests that lie outside the standard AP curricula. A good majority of these students (about 90%) remain interested in science and mathematics and go on to major in these areas of study in top colleges around the country. In addition, approximately 95% of all graduates who have taken the Chemistry/Physics Program have reported in surveys that they definitely feel better prepared for college and careers not only because they had college-level material in high school, but also because of the study skills and time-management skills they developed by taking on multiple challenges that were offered outside of the standard curricula. It is imperative that we continue to challenge our best and brightest even in times when it seems there are fewer resources being allocated for them. In some cases, teachers must take it upon themselves to get these students involved in studies and activities that will allow them to take advantage of their gifts and develop into the next generation of scientific leaders.

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Appendix
Web Sites

American Association of Physics Teachers
http://www.aapt.org

Chemistry. Org: American Chemical Society
http://www.acs.org

Intel Education: Intel Science Talent Search
http://www.intel.com/education/sts

International Embryo Transfer Society
http://www.iets.org

International Society for Horticultural Science
http://www.ishs.org

National Science Bowl
http://www.scied.science.doe.gov/nsb/default.htm

Siemans Foundation
http://www.siemens-foundation.org/science/default.html

Worldwide Youth in Science and Engineering
http://www.engr.uiuc.edu/wyse